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Materials Science in Europe:
A Summary Report

Kenneth D. Challenger

June 27, 1986

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MATERIALS SCIENCE IN EUROPE: A SUMMARY REPORT

1 INTRODUCTION

For this summary, I will review a few research topics actively pursued in Europe where the results could be of benefit to the US. The highlights I have chosen certainly do not include all materials-related topics in this category, but only those with which I have become familiar. They include: welding science and technology, composite materials, fracture mechanics, ceramics, and a few other specialized topics presented in the miscellaneous section.

2 WELDING

I will not highlight the welding research in this report because I have already done so in two separate assessment reports (see ONRL report R-2-86 and R-3-86). Suffice it to say that there are excellent research programs in the UK, Scandinavia, West Germany, and Eastern Europe that are well worth following. In fact, the researchers at the Technical Research Center of Finland (VTT) are anxious to start some collaborative research. With their experience in offshore platform and ship construction, collaboration could be very beneficial to the Navy. The UK Welding Institute is performing more basic research on welding (really only quasi-basic, but as close to basic as one gets in Europe) than anyone else in Western Europe.

All of the welding research in well coordinated in Western Europe. US investigators appear to be poorly informed with respect to this research. One method to rectify this situation is for US researchers to play a more active role in the International Institute of Welding (IIW). IIW has a significant input from Eastern European countries which has obvious advantages and disadvantages with respect to an increase in US participation. In my opinion, such participation represents an easy way to stay abreast of the developments in this field worldwide.

3 FRACTURE MECHANICS AND FRACTURE MECHANISMS

Most of the European countries have large research and development programs in fracture mechanics and fracture mechanisms. This research is motivated by the requirements of the offshore oil, electrical power generation, and aerospace industries. In general, the best programs are carried out either by or for the electrical utilities: the Central Electricity Generating Board (CEGB) in the UK; CISE, the research arm of the Italian electricity generating board; the West German and Materials Testing Institute (MPA), which supports nuclear power in West Germany.

The current emphasis of the research is on the analysis and characterization of elastic-plastic fracture, dynamic fracture, and large-scale component-like testing.

The UK and French Welding Institutes both have large programs in support of the offshore oil industry. Much of the research is similar to or, in fact, follows the lead of research in the US, specifically, the ASME code activities.

The analysis methods of the CEGB Leatherhead Laboratory (Drs. I. Mogford and I. Milne), deal with fracture over the range of conditions that lead to brittle, ductile, and transitionary fracture are, in my opinion, the best in Europe. They are perhaps less sophisticated than the methods used in the US, but they seem to work well and are based on sound physical principles (see *ESN* 38-8:432-434 [1984]). West Germany is probably spending more on this topic than other country in Europe, and the results are beginning to show, especially in dynamic fracture and large-component testing. Professor Kussmaul's laboratory at Stuttgart (MPA) and Professor Sommer's laboratory at Freiburg (Fraunhofer Institute for Material Mechanics) are world leaders in dynamic fracture mechanics (see *ESN* 39-4:152-156 [1985] and *ESN* 40-5:157-162 [1986]). Both have unique testing facilities and are interested in collaboration with the US.

(Note: Dr. J. Gudas, DTNSRDC, will be spending 1 year with Sommer's group beginning the summer of 1986. This will be very beneficial to the US Navy's programs in this area.) Other notable but less significant programs on fracture mechanics exist at the École des Mines de Paris (Dr. A. Pineau, see *ESN* 40-3: 95-97 [1986]); Institute Soete, University of Gent (Dr. A. Denys, see *ESN* 39-8:375-378 [1985]); and the Technical Research Center of Finland (see *ESN* 40-6:203-207 [1986]). The micromechanisms of fracture are investigated to a limited extent in all of these programs, but the most significant effort on this topic is performed by Dr. J. Knott and his students at the University of Cambridge (see *ESN* 38-9:491-492 [1984]).

In my opinion, the US has the most to gain by collaborating with, or at least following the developments of the research at MPA, Stuttgart, Fraunhofer Institute for Material Mechanics, Frieburg, and Dr. J. Knott's work at the University of Cambridge. At the moment, the Fraunhofer and Cambridge research is closely followed (Navy visitors working with each of these research group) but the MPA work is not. Perhaps Dr. Gudas can follow up my contacts with Kussmaul while he is in Frieburg.

4 COMPOSITE MATERIALS

Composite materials fall into the category of advanced materials and thus are part of the bandwagon that almost everyone in the the materials community in the the Western World is leaping for at the moment. The sudden attraction of materials scientists to advanced materials is, of course, caused by a redirection of funding sources. This is causing a somewhat disconcerting shift away from research on the more traditional materials, in the sense that strategically we must continue to produce alloys of steel, aluminum, and other metals which are equal to the best quality available anywhere. Without support for research and development of these materials the West will fall (even further) behind Japan and Eastern Europe. The Eastern European countries, whether due to the sluggish response to demands, or by design, continue to have major research programs for developing conventional alloys.

Here is one example of the reason for my concern: The UK was once a leader in quality steel production; classic metallurgy was taught at several universities, and there were several chairs of metallurgy around the country. Today, Professor J. Nutting, Leeds University, is the last one. When he retires it is unlikely that the chair will be filled by a classical metallurgist. And further, Professor Nutting spends a lot of his time in India teaching them how to make steel and how to train ferrous metallurgists.

In my opinion, a proper balance between advanced materials and conventional materials is required but, whether good or bad, all of the excitement and action in the materials community in Europe concerns "advanced materials." These include metal alloys made by novel processing methods, such as rapidly solidified materials or powder metals, composite materials, and high-performance ceramics.

In the past year I have made an attempt to complement the survey of composite materials made in 1983-1984 by Tsu-Wei Chou. Based on his review and my information I have reached the opinions and observations that follow.

West Germany

Dornier and Messerschmitt Bölkow-Blohm (MBB) are rapidly gaining the most experience in the design and fabrication of large load-bearing structures made from carbon-fiber reinforced epoxy. Look for them to be major participants in the EUREKA program (the European program for technical cooperation). Their interest in the development of the fibers is at a standstill while they focus on the development of improved matrix materials. The lightweight high-speed trains development that is a proposed thrust of EUREKA is very attractive to them.

West Germany's Federal Ministry of Research and Technology (BMFT) 1986 publication included materials development

as a key technology, and funds it at DM176 million (~\$80 million), up 8.6 percent over 1985. Most of this funding is for research on composites and ceramic materials. This level of funding places materials development on a par with biotechnology and aviation, but a long way below information technology (DM772 million--~\$382 million). Thus, the West German focus on composites is shared by industry and government. In fact, a new Max Planck Institute was recently created in Mainz for research on polymers.

Most of the research and development of these materials in West Germany must be done in the industrial laboratories because, while I found some active research in the German Aerospace Research Establishment (DFVLR) laboratories, I did not see enough to support the obvious growth of this industry in Germany (see *ESN* 39-9:423-427 [1985] and *ESN* 39-11:510-514 [1985]).

UK

The Royal Aircraft Establishment (RAE) at Farnborough, UK, has accumulated a large data bank of information on the mechanical performance of carbon-fiber reinforced plastics, including some data on the newest, most exciting matrix material developed by Imperial Chemical Industries (ICI) called PEEK (polyether keytone). Everyone seems to be testing this material with the view to replacing the thermosetting resin matrix materials in many applications. The data bank at the RAE should be of considerable interest to US investigators because it allows the results from laboratory-size test specimens to be correlated with the results of tests using large-scale structures; these data are scarce at the moment. (See ONRL report C-15-85, for details.)

I expect some great things from Professor D. Hull (the new Goldsmith Professor at the University of Cambridge--replacing Professor R.W. Honeycomb) with respect to understanding the mechanisms of failure in fiber-reinforced composite materials. He is only just starting at Cambridge but, based on his work at Liverpool, he is a man to watch. There is potentially a powerful team (Hull, Asby, Beaumont, and Knott) at Cambridge for studying failure mechanisms in composites, but it is yet to be seen if they can work together.

France

The French lead the Europeans in the development of ceramic matrix composites. Their experience with carbon/carbon composites for the Ariane rockets will pay off. Most of the French experience is centered in the SEP, the European propulsion company.

SEP carbon/carbon technology is very advanced, and SiC-fiber reinforced SiC materials can be made by a similar gaseous infiltration process. Initially SEP will be using SiC fibers produced by Nippon Carbon. The heat shield for Hermes, the French design for a manned space shuttle, will use a SiC/SiC composite made by SEP. These tiles weigh only 15 kg/m^2 as compared to the US space shuttle's tiles which weigh 40 kg/m^2.

Carbon-fiber technology and carbon-fiber reinforced composites are rapidly developing in France. Pechiney has a licensing agreement with Toray, the Japanese firm, to produce carbon fibers. The present capacity is 300 tons per year, but this will increase to 600 tons per year in the near future. These fibers will replace the fibers currently imported from Japan.

The French are actively involving their universities in the research and development of composite materials. This will solve one problem that has been slowing down the application of these materials worldwide; namely, a general lack of familiarity on the part of designers with the advantages of these materials and how to best use them. The composite material research at the French Universities is described in *ESN* 40-6:201-203 (1986). Dr. A.R. Bunsell at the École des Mines de Paris is the central university figure in the development of these materials. It will pay to stay in touch with him in order to keep abreast of the French developments

in composites. He will be visiting ONRHQ, NRL, and NSWC in October 1986 as a participant in ONRL's Visiting Scientist Program.

As an example of France's commitment to develop a strong composite materials industry in France, the Composite Materials Institute was formed in Bordeaux in 1983. It was formed by a cooperative agreement among public authorities, Bordeaux University, and several big industrial groups (SEP, Elf, Dassault, and Aerospatiale). Its main mission is to provide assistance and technology transfer to small and medium-sized French businesses.

Comments

The US seems to have a good arrangement with the UK on the exchange of technical information in this field via the TTCP. However, France and Germany have at least as much and probably more to offer than the British. They are rapidly gaining practical experience with these materials (for Ariane, Airbus, military aircraft, Hermes, and the new high-speed trains), and they have a strong government and industrial commitment to the development of these materials. It would be worthwhile to pursue a technical exchange agreement with either of them.

Other composite materials programs exist throughout Europe, but they are following the lead of the US, the UK, France, and West Germany.

5 CERAMICS

I have not spent much time surveying the research activities on these materials, but my successor at ONRL, Dr. Louis Cartz, plans to do so. I have come across some noteworthy research and have formed some opinions of where to watch for the best results.

The UK led in the research efforts on ceramics in the 1970's, but when only a few industrial applications were found their interest dwindled. The US, Japan, France, and West Germany were encouraged by the results of the British research and all three have launched major research programs. Now Britain has reentered the field. France has some 10 research teams in this field at the National Center for Scientific Research (CNRS) laboratories.

The development of these materials is being encouraged by the EUREKA program. One of the two major focus topics of EUREKA is the development of a small (500 to 1000 horsepower), but highly efficient terrestrial gas turbine. This will require the use of ceramics in the high-temperature turbine section. Another commercial application of ceramics that will soon appear is in the design and construction of diesel engines.

UK

Britain has provided seed money to a club of gas turbine designers led by Rolls Royce, and a similar automobile club is lobbying for similar treatment. The funding is small, however, and it appears likely that industry will have to put up most of the money. This means that the research effort will be quite limited for the near future because British industry is struggling at present. Leeds University (Prof. R. Brook) appears to have the largest university research program on ceramics in the UK.

West Germany

In my opinion the only European country with a chance to catch Japan is West Germany. She has money and is spending it on research. The decline of nuclear power research in West Germany has freed a lot of funding for other topics. Biotechnology, advanced materials, and information technology research will prosper for many years to come in West Germany.

Professor Bunk (DFVLR, Cologne) and his people will play a major role in the applied research on these materials (*ESN* 39-11:510-514 [1985]), and Professor G. Pezow at the Max Planck Institut für Metallforschung, Stuttgart (Professor H. Fischmeister, Director) will play a large role in the basic research on these materials.

France

France also has a commitment to the development of these materials,

especially the fiber-reinforced ceramics. SEP has the capability to manufacture SiC fibers, but at present they are inferior to Nippon Carbon fibers (by their own admission). The research group at the École des Mines de Paris (*ESN* 40-3:95-97 [1986]) is a center for university research on these materials.

The University of Limoges offers the only degree in ceramics science and engineering in France. Additionally, Limoges is a traditional center for porcelain and enamels and is making a bid to become France's ceramics hub. The university and The National Higher Education School for Industrial Ceramics collaborate with the now CNRS ceramics laboratory, which now has more than 50 permanent employees. About 5000 people are currently employed in ceramics-related industries in Limoges. Thus, it is a place to watch for new developments with these materials.

Sweden

Sweden's Silicate Research Center is another leader in the development of ceramics in Europe. I have not been there, but I know that their research is well respected throughout Europe.

6 MISCELLANEOUS TOPICS

Powder Metallurgy

In my opinion, the research at Metallwerk Plansee, Reute, Austria, is the best powder producer in Europe, especially for refractory metals. They have not entered the field of rapidly solidified powders, but do support a lot of university research in the German-speaking regions of Europe.

Asea (Sweden) is building (1987) a new plant specializing in powder metallurgy. It will have the world's largest hot isostatic press.

Dornier is developing powder metal aluminum alloys based on the standard Al-alloys 2024, 7075, X7090, and X7091.

MBB is developing powder metal Al and Ti alloys. Experimental parts for the Airbus in Ti-6Al-4V and Al-Li have been produced.

DFVLR, Cologne, is involved in some basic studies on sintering and compaction mechanisms of metal powders.

Al-Li Alloys

One of the most talked about categories of new metal alloys on the market is the Al-Li alloy system. Pechiney (France) and Alcan (UK) lead the development in Europe and are in direct competition with Alcoa. Most of the research on these alloys is done in-house and the results closely guarded. It is almost certain that Al-Li alloys will be perfected and find widespread use in the aerospace industries. Collaboration in any form is impossible at the moment, but once the alloys are formally approved for use in aircraft, their development should become more open, and collaboration between the US, France, and UK may become worthwhile.

Materials in Space

Space processing of materials on a commercial basis is, in my opinion, in the distant future, at best. However, microgravity is proving to be a useful environment to study some phenomena that cannot be studied otherwise--crystal growth, for example. West Germany has committed more than any other European country to experiments in space. The Spacelab experiments were poorly planned and somewhat crude but did produce some useful information on basic mechanisms of crystal growth and liquid-phase diffusion (see *ESN* 39-3:90-95 [1985]). The Germans seem committed to continued experimentation in space (the D-1 mission results should appear soon) but the Challenger catastrophe will delay the program. West Germany is covering all bets in space science at the moment by collaborating with NASA, the European Space Agency (ESA), and bilaterally collaborating with the US and France. West Germany provides 20 percent of the development costs for the French carrier rocket, Ariane; the new Ariane 5 is estimated to cost a total of about $2.2 billion. The Germans play a major role in the development of Columbus, the European space station (now a joint West

German, Italian, and French project. In all, the West German 1985 budget for space research was over DM800 million ($\sim$\$360 million) and growing each year. I do not know how much of this is allocated for materials processing in space.

The best way to keep abreast of the materials-in-space efforts in Europe is to keep in touch with Professor B. Feuerbacher, director of the DFVLR Space Simulation Institute in Cologne.

Silicon Metallurgy

Finland is moving into Si wafer technology (*ESN* 40-2:59-60 [1986]). Outokumpu and Nokia are financing the formation of a new Finnish company, Okmetic, which will produce Czochralski silicon wafers by techniques developed by Professor V. Lindroos at the Helsinki Technical University. This is a major effort and should be closely followed.

7 CONCLUDING REMARKS

There is a lot of good science happening in the materials area in Europe; however, with only a few rare exceptions the Europeans follow the lead of the US investigators. Most Europeans are very aware of the US research on their topics, but I do not feel that the reverse is true.

The research climate is healthy in France, West Germany, and Scandinavia (where it may change soon due to the depressed oil prices). The research budgets in the other European countries seem to be shrinking. However, materials research is as strong as any other topic in all the countries. Several efforts have been made (by, for example, the EEC and EUREKA) to develop a research base that includes all of the Europeans, but nationalistic behavior of each country is still preventing a combined and coordinated European science community. It is a worthwhile goal, but at the present seems out of reach.

West Germany and France lead in the development of materials, with Italy, the UK, and Scandinavia making significant but lesser contributions. I strongly recommend that my successor focus on France and West Germany for this reason. One could easily spend 2 years reviewing the materials science research in these two countries alone. Much of the research is done in private industry. This creates two problems for my successor; first, it is difficult to determine who is doing the research and second, once you know who it is, they are usually reluctant to talk. This is understandable, and I did not press the issue when I visited private firms. I had planned to make many more visits to industrial laboratories than I actually did. I found it so difficult to learn much about their research when I was invited to visit that I did not feel it worth my time. I do not know the solution to this problem; perhaps encouraging the industrial researchers to participate in our Visiting Scientist Program would encourage them to speak more freely.

Ceramics, composites, and novel processing methods for materials are the three most important materials science topics to be followed by ONRL scientists.

I have not mentioned much about research in Italy in this summary report. The reason is that I have attempted to highlight the best research which I have seen in Europe, and at the moment this does not include any Italian research in my field. But, be aware that Italian research seems to be improving and that, if the trend continues, Italy will surpass the UK in technological importance in Europe. A poorly organized government policy is all that hinders progress in Italy; the talent is there.

The great size and strength of the science and engineering base in the US has become especially impressive to me during my 2 years in Europe. Europe expects and depends on the US wealth and energy to pull its technology forward. I feel fortunate to live and work in the US.

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